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Life Cycle Assessment of Thai organic Hom Mali rice to evaluate the climate change, water use and biodiversity impacts

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ABSTRACT

Life Cycle Assessment (LCA) of Hom Mali organic rice production in Surin province, Thailand was performed to evaluate the potential environmental impacts. The scope of study was the farm gate and the functional unit was set as one kg of organic paddy rice. The inputs and outputs were collected from the farm's data recording including the measurement of water levels inside the rice field which was done over the production cycle along with methane and nitrous oxide emissions. Inventory analysis of fauna and flora before, during and after crop production was also performed. Carbon and water footprinting were based on the ISO methods, whereas the Swiss Agricultural LCA method was used for biodiversity impact assessment. The results revealed that the impact on climate change was 2.88 $kgCO_2eq$ per kg of paddy rice. The calculation of impact on water use with consideration of the water stress index of Mun watershed was 1.34 m^3H_2Oeq. The biodiversity impact assessment was found to be practical but largely dependent on the expertise and experience of the assessors. The results from this study have given the insights on how to anticipate the environmental product declaration for rice.

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1. Introduction

"Hom Mali" (Jasmine) rice is a key product significantly contributing to the socio-economic benefit of Thailand. The annual production of rice in Thailand is about 15.8 million tonnes and it ranks as the sixth largest rice producer in the world (USDA, 2017). The export of rice is valued at 155,912 million baht for the national revenue (OAE, 2016). The main production site is in the Northeast region comprising almost half of the total agricultural area and contributing to 60% of the total national production. At the same time, rice cultivation activities are highlighted as a major source of greenhouse gas (GHG) emissions from the agricultural sector, which ranks after energy production and industry operation, respectively. The GHG emission from the agriculture sector was 52.92 $TgCO_2eq$ in 2011, equivalent to 23% of the total GHG emissions (ONEP, 2015). Rice farming contributes to the methane emission from the agricultural sectors almost 58% compared to other sources from agricultural activities. Water consumption for rice cultivation, especially for Hom Mali rice, is also raised as a concern as it requires a wetland system maintained for at least one month during the production cycle. Stress on water resources is also linked to climate change impacts. Impacts on eco-toxicity and biodiversity losses are additional issues of concern for the environmental sustainability of rice production systems.

Life Cycle Assessment (LCA) is an analytical environmental tool to assess the potential impacts (i.e. environmental footprints) associated with inputs and outputs of product systems from cradle-to-grave. LCA has been adopted in several previous studies to assess the environmental performances of rice production with the focus on global warming. Previous LCA studies on milled rice in Thailand reported that the impact on global warming was mainly from the cultivation stage (95%), followed by the harvesting stage (2%) and milling stage (2%) (Kasmaprapruet et al., 2009; Arunrat et al., 2016).

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Methane was the pre-dominant GHG emitted from the rice field, followed by the GHG emissions from on-farm machinery use based on the LCA study of rice cultivation in the Eastern-Gangetic plains, India (Alam et al., 2016). It was also revealed by Thanawong (et al., 2014) that the global warming potential was higher in the dry-season irrigated rice farming systems (5.55 $kgCO_2eq$ per kg of paddy rice) compared to the wet-season irrigated rice farming systems (4.87 $kgCO_2eq$ per kg of paddy rice) in Thailand. In China, the carbon footprint of five main rice-growing regions in China were 2504.20 $kgCO_2eq/t$ (Guangdong province), 2326.47 $kgCO_2eq/t$ (Hunan province), 1889.97 $kgCO_2eq/t$ (Heilongjiang province), 1538.90 $kgCO_2eq/t$ (Sichuan province) and 1344.92 $kgCO_2eq/t$ (Jiangsu province) respectively (Xu et al., 2013).

Organic farming is an alternative system for more sustainable rice production and being promoted due to perceived, lower risks from chemical use and having a potential to reduce environmental impacts including biodiversity losses. At the same time, it offers lower production costs and higher price (BRRD, 2014). Thus, there has been an interest in evaluating the environmental performance of organic rice but rather limited to global warming and ecosystem degradation. Yodkhum et al. (2017) conducted the LCA study and reported that the carbon footprint of organic rice production in the North of Thailand was 0.58 kg CO_2eq per kg of paddy rice where the major source of GHG emission was from the field emissions. Nunes et al. (2016) reported that the organic white rice in Brazil had the highest global warming potential (35.53 kg CO_2eq/kg of protein, followed by the organic brown rice (26.50 kg CO_2eq/kg of protein) and the minimal white rice (15.80 kg CO_2eq/kg of protein). It was also stated that the organic production contributed less to local ecosystem degradation (Nunes et al., 2017).

Environmental product declaration is likely to be in demand for international trading. Particularly for agri-food products including rice, the key environmental information that will be required is: carbon, water and biodiversity footprints. At this stage, the two types of carbon footprint labels are in place in Thailand: 1) carbon footprint label (carbon score, the life cycle GHG emission) and 2) carbon footprint reduction label (% reduction of carbon footprint value comparing to the previous year or the last 2 years, else the carbon footprint value must be equal or lesser than the benchmarking value announced by the authorized organization). Water footprint label is not yet in place, but it is in a preparation stage. In terms of biodiversity footprint, it is still in a great doubt how to quantify it. To this end, an LCA study was performed to evaluate the potential environmental impacts of organic rice production in Thailand. The results of LCA could be used to anticipate the Environmental Product Declaration to support the market requirements for the industry, including the discussions and outlooks on practical issues to consider.

2. Material and methods

2.1. Studied site

The studied site was a 1.28 ha organic rice field in Surin province, which is the key production area of Hom Mali rice in the Northeast region of Thailand. This rice field has been certified as an organic farm from the Organic Agriculture Certification Thailand (ACT) in accordance to its organic standard for 10 years already. The rice field's location is outside the irrigated zone; so the rice farming is totally dependent on rainfall and only a single crop is cultivated every year.

The initial land preparation was begun after the previous harvest. It was performed by ploughing the whole area one time before adding the green manure (cattle manure) at the rate of 7500 kg ha^{-1}. After that, it was ploughed up and over and the field left idle for at least 3 weeks. Ploughing was then repeated to provide a smaller and soft soil mass for dry broadcast seeding. Seeds were taken from the previous crop, in this case, and spread over the field at the rate of 93.75 kg ha^{-1}. During the cultivation period, weed control was achieved manually. The production cycle was 120 days to obtain a yield of **2**581 kg ha^{-1}. The average value of good rice grains per year of rice is 93.31% (humidity 14%), and the average weight of 1000 grains is 27.75 g. The harvesting was done mechanically. After harvesting, paddy rice was transported from the rice field to the rice mill over a distance of 8 km using a 6-ton truck. The humidity level and contaminants were inspected. The harvested rice paddy with a humidity of 20% was left for sun drying to reduce the humidity to 14%. The rice milling processes started from the de-hulling to remove hull and bran layers from paddy rice to obtain brown rice. Then, unhusked and brown rice were separated using separators. White rice was produced by polishing three times and whitening two times. Head rice, large and small broken rice were separated and graded for further packaging. The typical packing size is 1 kg in vacuumed polypropylene bag.

The studied site has a loam soil with acidic condition (pH = 4.7) containing silt as the main component (Table 1). Based on the testing of soil samples from the rice field, it was found that the soil properties offer a good organic matter level with nitrogen at 0.07%, whereas the levels of phosphorus and potassium are rather low as it is a sandy soil (Land Development Department, 2013). The water can be discharged easily in this soil type and condition. The chemical characteristics of cattle manure used in this rice field indicated a high nitrogen, phosphorus and potassium content (Table 2).

2.2. LCA study

The LCA method applied in this study referred to the step-by-step method defined in ISO 14040 (2006) and ISO 14044 (2006) as follows.

2.2.1. Goal and scope definition

The goal of this LCA study was to support the rice industry on anticipating the Environmental Product Declaration in terms of carbon, water and biodiversity footprints to support the market requirements for the rice industry. The studied product is 1 kg of white milled Hom Mali rice in vacuumed polypropylene bag. Fig. 1 shows the system boundary that included the rice farming (at the rice field) and rice milling and packing (at the factory).

2.2.2. Data collection

For the farming stage, the inventory data (foreground data) were mainly the primary data collected through the interviewing of farmers (Table 3). The background data associated with the diesel production was taken from the ecoinvent database and GHG emissions were sourced from the IPCC guideline (IPCC, 2016). In a

Table 1
Characteristics of soil in the studied site.

Parameters of soil	Amount
Soil texture	loam
Sand (%)	34
Silt (%)	48
Clay (%)	18
pH	4.7
Organic matter (%)	1.18
Nitrogen (%)	0.07
Phosphorus (ppm)	7
Potassium (ppm)	46

Table 2
Chemical characteristics of organic fertilizer (cattle manure).

Chemical characteristics	Amount
Moisture (%)	30.41
Nitrogen content (% dry weight)	1.58
Phosphorus content (% dry weight)	0.43
Potassium content (% dry weight)	0.75
Organic Carbon (% dry weight)	18.25
C/N	12:1

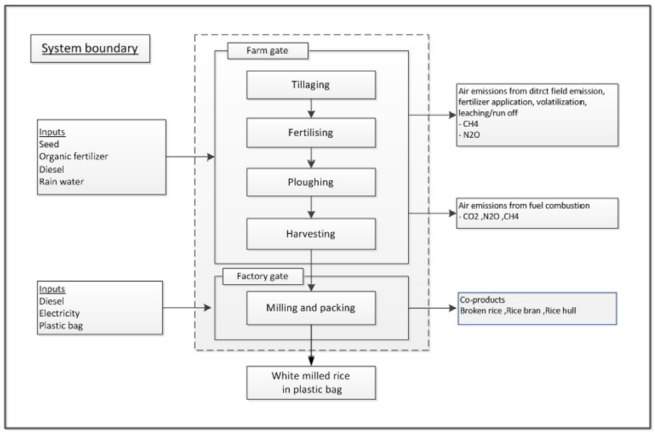

Fig. 1. System boundary of the LCA study.

similar manner, for the milling stage, the inventory data (foreground data) were mainly the primary data collected through the interviewing of farmers (Table 4). The background data associated with the electricity production was taken from the Thai national database and the plastic production was taken from the ecoinvent databases.

The co-products at the milling stage were: broken rice and rice bran. Economic allocation was applied based on the revenue gained from different rice co-products: head rice (40 baht per kg), broken rice (15 baht per kg), rice bran (1.5 baht per kg), and hull (1.5 baht per kg). As a consequence, the % allocations to head rice, broken rice, rice bran and hull were 84%, 15%, 1% and 1% respectively (Table 5).

2.2.3. Impact assessment

2.2.3.1. Carbon footprint. The life cycle GHG emissions were calculated by applying the LCA methodology and adopting Product Category Rules (PCR) of rice product described in the Thailand Greenhouse Gas Management Organization (Public Organization) (TGO, 2013). The PCRs have defined the scope of analysis that could be cradle-to-farm gate as well as cradle-to-factory gate the functional unit should be expressed as the weight per specific package as sold unit. It is required that the inventory data must be from primary sources if the activities are under operational control and from secondary data if not under operational control. The direct methane emissions from the rice field are based on country specific emission factors (Tier-2 methodology) and Nitrous oxide emissions from fertilizer application are based on Tier-1 methodology; for the GHG emissions, the GWP100 (100-year time horizon), of CO_2, CH_4 and N_2O are applied (IPCC, 2006, ISO 14044, 2006). The background data are primarily sourced from the national databases and the international databases can be used to substitute if the required data are not available in the national databases. Biogenic carbon is excluded from the calculations. Land use change should be calculated and reported separately, in case that the land is converted from forest to agricultural lands; unless there is a proof on land history that has been using for agricultural lands continuously for more than 10 year; then the land use change can be excluded (see Tables 6–10).

Equation (1) below is used for calculating the life cycle GHG emissions:

$$E_{\text{Total GHG}} = E_{\text{input}} + E_{\text{electricity}} + E_{\text{fuel production}} + E_{\text{fuel combustion}} + E_{\text{fertilizer application}} + E_{\text{CH4 direct field emission}} \quad (1)$$

Where

$E_{\text{Total GHG}}$ Total GHG emission from the entire of life cycle of Organic Hom Mali Rice ($kgCO_2eq/kg$)
E_{input} GHG emission from material production ($kgCO_2eq/kg$)
$E_{\text{electricity}}$ GHG emission from electricity production ($kgCO_2eq/kWh$)
$E_{\text{fuel production}}$ GHG emission from fuel production ($kgCO_2eq/L$)
$E_{\text{fuel combustion}}$ GHG emission from fuel combustion ($kgCO_2eq/kg$)
$E_{\text{fertilizer application}}$ N_2O emission from fertilizer application ($kgCO_2eq/kg$)
$E_{\text{Direct field emission}}$ CH_4 emission from rice cultivation ($kgCO_2eq/kg$)

Equation (2) below is used for calculating the indirect GHG emissions associated with raw material acquisition, electricity production, fuel production:

$$\text{GHG Emission } (kgCO_2eq) = \sum_{i=1} A(i) \times EF(i) \quad (2)$$

Table 3
Data sources (the farming stage).

Item	Type of data	Data source
Land	Foreground	Interviewing
Seed	Foreground	Interviewing
Seed production	Background	ecoinvent 3.0 database
Cattle manure	Foreground	Interviewing
Diesel use	Foreground	Interviewing
Diesel production	Background	ecoinvent 3.0 database
Rain water	Foreground	TMD (2014)
GHG emission from diesel combustion	Foreground	IPCC (2006)
GHG emission from field emission	Background	IPCC (2006)
GHG emission from fertilizer application	Background	IPCC (2006)

Table 4
Data sources (the milling and packing stage).

Item	Type of data	Data source
White milled rice, broken rice	Foreground	Data record
Rice bran, rice hull	Foreground	Data record
Electricity consumption	Foreground	Data record
Electricity production	Background	Thai national database
Plastic bag use	Foreground	Data record
Plastic bag production	Background	ecoinvent 3.0 database
Diesel use	Foreground	Data record
Diesel production	Background	ecoinvent 3.0 database
Air emissions from fossil fuel combustion	Background	IPCC (2006)

Table 5
Percent allocation based on the economic values.

Product	Mass (kg)	Price (baht/kg)	% allocation
White milled rice	65,077	40	84
Broken rice	11,357	15	15
Rice bran	533	1.5	1
Rice hull	908	1.5	1

A(i) Amount of raw materials (unit: kg), electricity (unit: kWh), and fuel (unit: L)
EF(i) Emission factor ($kgCO_2eq$/unit)

2.2.3.2. Water use. The calculation method of water use impact refers to the method defined in ISO 14046 (ISO, 2014) as well as the water scarcity footprint reported earlier. The ISO methodology has recommended that water footprinting must be based on the life cycle water inventory with consideration of watershed-based water stress. The water stress indices of 25 watershed-based areas for Thailand has been reported by Gheewala et al. (2014).

The equation below is used for calculating the water scarcity footprint:

$$\text{Water scarcity footprint}_{(\text{rice, surin})} = \text{Irrigation water use}_{(\text{rice})} \times \text{WSI}_{,\text{I}} \quad (3)$$

Table 7
The inventory data of milling and packing of 1 kg packed rice.

Input-output	unit	Amount
Electricity	kWh	0.14
Diesel	L	0.0012
Plastic bag	kg	0.0096
White milled rice in package	kg	1.0
Broken rice	kg	0.47
Rice bran	kg	0.22
Hull	kg	0.37
Air emissions (fossil fuel combustion)		
Carbon dioxide	kg	0.0033
Methane	kg	3.3E-06
Nitrous oxide	kg	8.0E-06

Table 8
Life cycle GHG emissions of paddy rice and white milled rice.

Life cycle stage	GHG emission ($kgCO_2eq$/kg)		GHG emission ($kgCO_2eq$/kg)	
	paddy rice	%	milled rice	%
1. Rice cultivation				
CH_4 direct field emission	2.62	91	4.47	84
N_2O direct field emission	0.11	4	0.18	3
Seed production	0.07	3	0.13	2
Organic fertilizer	0.05	2	0.09	2
Diesel production	0.00	0	0.01	0
Diesel combustion	0.03	1	0.05	1
2.Transport to rice mill			0.27	5
3.Milling and packing				–
Electricity			0.09	2
Diesel production			0.00	0
Diesel combustion			0.00	0
Plastic bag			0.07	1

Table 6
The inventory data of rice cultivation per crop (1.28 ha).

Inventory	Unit	Amount
Crop yield	kg	3296
Land	ha	1.28
Seed	kg	120
Rain water	m^3	2756
Cattle manure	kg	12,000
Straw residues	kg	5200
Diesel - (tillaging)	L	5
Diesel - (fertilising)	L	3
Diesel - (ploughing)	L	8
Diesel – (harvesting)	L	16
Air emissions		
Methane (direct field emission)	kg	389
Nitrous oxide (direct, fertilizer application)	kg	0.32
Nitrous oxide (indirect, volatilization from fertilizer application)	kg	0.92
Nitrous oxide (leaching/run off, from fertilizer application)	kg	1.91
Air emissions (fossil fuel combustion)		
Carbon dioxide	kg	87.44
Methane	kg	0.09
Nitrous oxide	kg	0.21

Table 9
GHG emission from the diesel used for field operation.

Production stage	GHG emission ($kgCO_2eq$)		
	CO_2	CH_4	N_2O
Diesel (tillaging)	4.36E-06	1.09E-04	3.13E-03
Diesel (fertilising)	2.18E-06	5.45E-05	1.56E-03
Diesel (land excavation)	6.54E-06	1.63E-04	4.69E-03
Diesel (harvesting)	1.31E-05	3.27E-04	9.38E-03

Water Scarcity Footprint: Water footprint with consideration of the water stress of area [m^3H_2Oeq/tonne]
Irrigation water: Quantity of irrigated water for cultivation [m^3H_2O/tonne]
Water Stress Index: 0.927

$$\text{Water demand for crop growing} = \frac{[\text{crop water requirement}] - [\text{effective rainfall}] + [\text{water loss}] \times 100}{[\text{irrigation efficiency}]} \quad (6)$$

$$ET_c = K_c \times ET_0 \text{ [mm/day]} \quad (4)$$

The ET_c is practically computed with regard to meteorological data and crop variety. According to variations of weather and crop species, a reference crop evapotranspiration (ET_0) and crop coefficient (K_c) are developed to be related to estimate the ET_c of any crops planted in any area and time. Regarding the K_c and ET_0 terms, the Penman Monteith method was mainly applied with local meteorological data to calculate the ET_0 values. The ET_0 values varied among different watershed and location (RID, 2011).

Crop Water Requirement (CWR) is the theoretical water required by the plant for its survival, growth, development and this requirement is applied either naturally by precipitation or artificially by irrigation. Water demand for crop growing is estimated based on the water required by crops and cultivated areas relating to effective rainfall, water loss via conveyance and irrigation efficiency as can be expressed in (5) below (RID, 2011).

$$CWR = 10 \times \sum_{d=1}^{lgp} ET_{crop} \quad (5)$$

Where

d - the period from the day of planting (day 1) to the day of harvest.
lgp – length of growing period in days (120 days)

Water required for growing crops in non-irrigated areas is supposed to be equal to the amount of rainfall used by crop so-called effective rainfall. If CWR is higher than effective rainfall, water withdrawal for field crops in non-irrigated areas is equivalent to the amount of effective rainfall. On the other hand, if effective rainfall is higher than CWR, water withdrawal for field crops in non-irrigated areas is equivalent to the amount of CWR. Water required for growing crops cultivated in irrigated areas are expected to meet total amount of crop water requirement. Thus, a sum of effective rainfall and irrigation water is accounted as the total water withdrawal for crops cultivated in irrigated areas. This irrigation water is defined as the additional amount of water required to reach the total amount of crop water requirement. Irrigation efficiency (IE) is the ratio of the amount of water consumed by the crop to the amount of water supplied through irrigation. In general, to calculate the amount of irrigation water requirement for irrigated agriculture, irrigation efficiency and water loss through percolation are taken into account as can be expressed in (6)

2.2.3.3. Biodiversity footprint. In terms of biodiversity, the inventory of terrestrial and aquatic organisms was collected by taking into account of the land use patterns around the nearby areas. Six sample points were included in this study. The inventory list of aquatic organisms covered invertebrates, phytoplankton, zooplankton, and fish. The water quality was also measured to have the background information of ecological conditions. For the assessment of biodiversity footprint, the integration of biodiversity (organismal diversity) as an impact category of Life Cycle Assessment (LCA) for agricultural production (SALCA-Biodiversity) developed by the Agroscope Reckenholz-Tänikon Research Station ART, Switzerland was selected to explore if it would be workable under the local context. Normally, the biodiversity potential of each indicator in terms of species diversity and species composition is determined in two steps. First, agricultural activities are rated on the basis of their effects on the organisms. Second, the defined habitat types are weighted according to their importance for the indicators. The final scores are yielded by multiplying the ratings from steps one and two (Jeanneret et al., 2014). However, in this study it has been applied only at the conceptual level. First, the local Indicator Species Groups: ISG (flora and fauna) were listed considering the site-specific species and associated potential environmental impacts. Second, rice farming management practices (mowing, fertilizer application and pesticide application) and the effect of management activities on each ISG were identified based on local assessors. Third, a scoring system estimated the reaction of every indicator species group regarding management options, followed by aggregation steps.

The calculation formula is based on (Jeanneret et al., 2008; Jeanneret et al., 2014) as follow;

$$S = R * Cf$$

Table 10
Life cycle GHG emissions.

Product	Total	GHG emission ($kgCO_2eq$)		
		Rice cultivation	Transportation to milling factory	Milling and packing
Paddy rice	2.88	2.35	–	–
White milled rice	5.34	4.92	0.27	0.16

Where

S = final rating,
R = impact rating of a management option (0–5) and
Cf = final coefficient = $[C_{management} + C_{habitat}]/2$

The value of a coefficient ($C_{habitat}$) ranging from 0 to 10 was given to weight the rating of the management options for each ISG as well as a coefficient ($C_{management}$) ranging from 0 to 10 to show the relative importance of each management activity such as mowing and fertilizer application. We then calculated the final score S of each management option as indicated in the formula above. The final ISG score of each rice farming system was calculated as the mean S over the management options (Jeanneret et al., 2008; Jeanneret et al., 2014).

3. Results and discussion

3.1. Inventory analysis

The inventory data analysis results showed that the organic rice farming required, 32 L of diesel, 12,000 kg of cattle manure, 2756 m^3 of rain water per crop of paddy rice; the direct emissions of methane was 389 $kgCH_4$ per crop of paddy rice and that of nitrous oxide from organic rice farming was 0.16 gN_2O per crop of paddy rice. It was found that the energy required for milling rice was 0.14 kWh/kg milled rice.

3.2. Impact assessment

3.2.1. Carbon footprint (life cycle GHG emission)

The life cycle GHG emission of paddy rice is 2.88 $kgCO_2eq/kg$ and that of white milled rice is 5.36 $kgCO_2eq/kg$. The main contributor for both cases is linked to the direct CH_4 emission from rice field, followed by the direct N_2O emissions. The CH_4 and N_2O emissions accounted for 84% and 3% of the total GHG emissions, respectively. The CH_4 emission was 30.41gCH_4/m^2/or 389 $kgCH_4$ per crop over the production cycle of 120 days. The N_2O emission was 2.48 kgN_2O/ha/crop. Compared to the previous cases of organic rice, it was revealed that there was a wide variation. For instance, the previous study reported the carbon footprint value was 0.58 kg CO_2eq per kg of paddy rice due to the use of baseline emissions from the IPCC Tier-1 method (CH_4) and Tier-1 method (N_2O) and the yield was rather higher (Yodkhum et al., 2017). The use of green manures from rice straw and cattle manure for increasing the nutrient level in soil could at the same time have a potential of increasing the CH_4 emissions from the rice field. Comparing to other studies, the results showed that the cultivation stage was the key hot spot with the highest contribution resulting from direct methane emission from the rice field (Nunes et al., 2017; Nunes et al., 2016; Jianyi et al., 2015; Thanawong et al., 2014). However, the carbon footprint value of this study (2.88 $kgCO_2eq/kg$) was similar to another study (2.97–5.55 $kgCO_2eq/kg$) in the Northeast region of Thailand (Thanawong et al., 2014). Similarly, the Chinese rice production showed a similar magnitude of GHG emissions ranging from 1.57 to 2.35 kg CO_2eq/kg of grain (Jianyi et al., 2015). The carbon footprint of rice from Iran was rather lower (1.47 $kgCO_2eq/kg$) due mainly to the about 1.5 times higher yield (Nunes et al., 2016). The variation of carbon footprint values resulted from the yield and crop management practices.

3.2.2. Water use impact

Rice is typically cultivated under a flooded system. The level of water during the cultivation period was approximately 10 cm and relied on rainfall only. The water inventory was 1.45 m^3/kg paddy rice (Tables 11 and 12). However, this did not reflect the real consumptive water. It was due to the requirement of flooded system during the production cycle especially over the booting and heading periods. By taking into account of the water stress index of Mun watershed basin (0.927) according to Gheewala et al. (2014), the water footprint value was 1.34 m^3/kg paddy rice.

There is a great concern over how to measure the consumptive water in rice field, especially rainfed rice farms. The amount of water level in a flooded system is totally dependent on the amount of rainfall. Moreover, the farmers do not always measure the water level inside the rice fields as far as it is flooded sufficiently to prevent pathogens and grass. For the irrigated areas, the amount of water level is dependent on the irrigation efficiency and the location of farms where the irrigation is sufficient or not. To some extent, the water footprint value is linked to the water resource management in a particular area. Thus, the water footprint value might not be used to indicate the real situation of water use impact.

3.2.3. Biodiversity impact

The field survey of biotic resources in organic rice fields showed the numbers of species, the density of phytoplankton, zooplankton and fish and the variety of species and their densities (Table 13) and the number of species of flora (Table 14). To assess the biodiversity score, the SALCA methodology was adopted. The indicator species groups (ISG) were then listed based on habitat type, spatial requirement, and function in the trophic chain as shown in Table 15. The ISG identified are phytoplankton, zooplankton, benthos, invertebrates with plants, and fish. Activities affecting biodiversity are - land preparation (land excavation of rice straw and using of green manure), fertilizer application based on the frequency (0, 1–2, 3–4, 5 or more), type (chemical or biological fertilizer), and application rate in tonne per ha (0, 1–2, 3–4, 5 or more) herbicide application, pesticide application. The biodiversity scores of organic rice were in similar magnitudes for all organisms, except for zooplankton and phytoplankton (Table 15). Zoo plankton is three orders of magnitude higher than benthos, while phytoplankton is almost 15 times higher than zooplankton.

The biodiversity impact assessment based on SALCA was found to be practical but largely dependent on the expertise and experience of the assessors. The identified activities associated with rice farming practices did affect species diversity and abundances of freshwater fauna. Organic rice farming system promotes and increases a wide variety of aquatic flora and fauna. This is relevant to the study conducted in north-western of Costa Rica revealing that there were a greater number of families and species of macroinvertebrates in the organic treatment than in the conventional treatment (Federico Rizo-Patron et al., 2013). The main effect that decreases biodiversity especially zooplankton is the use of pesticide and insecticide. Pesticides directly affect the population dynamics of zooplankton by affecting individual death and reproduction, and by altering the sex ratio as well as increasing predation risk by changing swimming behaviour and morphology (Hanazato, 2001; Chang et al., 2005).

Different species composition was also observed between organic and non-organic rice fields. Some macro-invertebrates resistant to pollution such as Culicidae were present in the non-organic compared to the organic fields. Overall, our results based on SALCA were consistent with the impact assessment of agricultural activities for the groups of grassland flora and fauna in grassland management systems in the Swiss lowlands. The calculated scores of each indicator species group (e.g. butterflies, wild bees and

Table 11
Water requirements for organic rice cultivation in Surin province.

Product	Yield (kg/ha)	Crop Water Requirement			Rainwater use (m3/kg)	Irrigation water required (m^3/kg)
		Rainwater use (m^3/ha)	Irrigation water required (m^3/ha)	Total (m^3/ha)		
Organic rice	2581	4713	3451	8164	1.83	1.34

Table 12
Water scarcity footprint for organic rice cultivation in Surin province.

Product	Water scarcity footprint m^3H_2Oeq/ha	Water scarcity footprint m^3H_2Oeq/kg paddy rice
Organic rice	3199	1.24

Table 13
Number of species and densities of fauna.

Organism	Organic rice	
	Number	Density
Phytoplankton (unit per litre)	85	152,206 ± 195,417
Zooplankton (unit per litre)	46	11,032 ± 12,070
Benthos (no per 256 cm^2)	8	14 ± 13
Invertebrates with plants	58	15 ± 13
Fish (no per 100 m^2)	11	46 ± 8

Table 14
Number of species of flora.

Organism	Organic rice
Free-floating plant	2
Terrestrial plant and aquatic plant (in the rice field)	30
Terrestrial plant (by the roads, 5 spots)	49

Table 15
Biodiversity score of organic.

Organism	Biodiversity score
Phytoplankton	23.63
Zooplankton	14.18
Benthos	16.36
Invertebrates with plants	12.31
Fish	13.81

grasshoppers) were lower in intensive grassland (5 cuts/year) than in extensive grassland (1 cut/year) indicating the management options had a major impact on biodiversity (Jeanneret et al., 2014).

4. Conclusions

In summary, the methodology of carbon footprinting is very well established, based on the LCA methodology defined in ISO 14040/14044, with specific rules for its application for carbon footprint calculation. In contrast, the methodology of biodiversity footprint is not yet standardized and the issues are rather sensitive for the local contexts of biodiversity conditions. The baseline of biodiversity is of a great concern and the losses of biodiversity could take a short, medium and long term to take place. For water footprint, the methodology is referred to the method described in ISO 14046 which highlights the consideration of water stress index. The adopting of water stress index could rather be useful for sourcing raw materials for manufacturing companies. The water footprint value is also dependent on the local water resource management and could not totally reflect the real consumptive water for some cases including rice. Especially for rainfed rice fields, there is a great concern over the water footprint as it totally relies on nature. The biodiversity footprint methodology is the most critical at this stage due as the methodology is not yet settled and it does not make sense to be labelled on the products unless the messages are clarified and be able to be understood by consumers.

5. Outlook

Based on the experiences gathered when conducting carbon, water and biodiversity footprints in this study, the following inputs can be gained vis-à-vis EPD development. Thailand is very well aware of the environmental product declaration that is required from overseas markets and at the same time being encouraged at the national level to support the sustainable product procurement policy. The carbon footprint label can be implemented to encourage the consumers to participate in combating climate change by purchasing the products with lesser carbon footprint values or from the climate-conscious manufacturers. For water footprint, it is still in doubt to be promoted in the country as it is pretty linked with local water resource management and should be effectively managed as the whole area taking into account of various plants as well as water demand for industries and households. In conclusion, environmental footprint label is being encouraged in Thailand to anticipate the market trend, but it must not cause a barrier to trade.

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